Sorbent Injection for Small ESP Mercury Control in Low Sulfur Eastern Bituminous Coal Flue Gas

Quarterly Technical Progress Report
October 1 – December 31, 2004

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Disclaimer

Abstract

This document summarizes progress on Cooperative Agreement DE-FC26-03NT41987, "Sorbent Injection for Small ESP Mercury Control in Low Sulfur Eastern Bituminous Coal Flue Gas," during the time-period October 1, 2004 through December 31, 2004. The objective of this project is to demonstrate the ability of various activated carbon sorbents to remove mercury from coal-combustion flue gas across full-scale units configured with small ESPs. The project is funded by the U.S. DOE National Energy Technology Laboratory under this Cooperative Agreement. EPRI, Southern Company, and Georgia Power are project co-funders. URS Group is the prime contractor.

Various carbon-based sorbents were injected upstream of low SCA ESP systems at Georgia Power's Plant Yates Unit 1 and Unit 2. Both Unit 1 and Unit 2 fire a low sulfur bituminous coal. Unit 1 is equipped with a JBR wet FGD system downstream of the ESP for SO_2 control. Unit 2 is not equipped with downstream SO_2 controls; however, a dual flue gas conditioning system is used to enhance ESP performance.

Short-term parametric tests were conducted on Units 1 and 2 to evaluate the performance of activated carbon sorbents. In addition, the effects of the dual flue gas conditioning system on mercury removal performance were evaluated as part of the short-term parametric test on Unit 2. Based on the results of the parametric tests, a single sorbent was selected for longer-term full-scale tests on Unit 1 to observe long-term performance of the sorbent, and its effects on ESP and JBR FGD system operations and combustion byproduct properties. The results of this study provide data required for assessing the performance, long-term operational impacts, and estimating the costs of full-scale sorbent injection processes for flue gas mercury removal.

This is the fifth full reporting period for the subject Cooperative Agreement. During this period, the long-term injection test was executed at Plant Yates Unit 1. Data reduction and analysis of collected samples was initiated.

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List of Acronyms

acfm	Actual cubic feet per minute
ACI	Activated Carbon Injection
APCD	Air pollution control device
APH	Air preheater
ASTM	American Society for Testing and Materials
CEM	Continuous emissions monitor
CO_2	Carbon dioxide
CT-121	Chyodia Thoroughbred - 121
CVAA	Cold vapor atomic absorption
ΔP	"Delta P", Pressure drop or pressure difference
DOE	Department of Energy
EPA	Environmental Protection Agency
EPRI	Electric Power Research Institute
ESP	Electrostatic precipitator
FGD	Flue gas desulfurization
FGD™	Norit America's Darco FGD™ activated carbon
HCl	Hydrochloric acid
Hg	Mercury
HOK	RWE Rhinebraun's Super HOK activated carbon
IGS	Inertial gas separation
JBR	Jet bubbling reactor
LOI	Loss on ignition
MW	Megawatt
NETL	National Energy Technology Laboratory
NH Carbon	Ningxia Huahui Activated Carbon
NH_3	Ammonia
NIST	National Institute of Standards and Technology
NO	Nitrogen oxide
NO_2	Nitrogen dioxide
NO_X	Nitrogen oxides
OH	Ontario Hydro
PSD	Particle size distribution
QA/QC	Quality assurance/quality control
SCA	Specific collection area
SCEM	Semi Continuous Emission Monitor
SO_2	Sulfur dioxide
SO_3	Sulfur trioxide
U.S.	United States

1.0 Executive Summary

This document summarizes progress on Cooperative Agreement DE-FC26-03NT41987, "Sorbent Injection for Small ESP Mercury Control in Low Sulfur Eastern Bituminous Coal Flue Gas," during the time-period October 1, 2004 through December 31, 2004. The objective of this project is to demonstrate the ability of various activated carbon sorbents to remove mercury from coal-combustion flue gas across full-scale units configured with small ESPs. The project is funded by the U.S. DOE National Energy Technology Laboratory under this Cooperative Agreement. EPRI, Southern Company, and Georgia Power are project co-funders. URS Group is the prime contractor.

Several carbon-based sorbent materials were injected upstream of low-SCA ESPs at Georgia Power's Plant Yates Unit 1 and Unit 2. Both Unit 1 and Unit 2 fire a low sulfur bituminous coal. Unit 1 is equipped with a cold-side ESP upstream of a JBR wet FGD system for SO_2 control. Unit 2 is not equipped with downstream SO_2 controls; however, a dual flue gas conditioning system is used to enhance ESP performance.

During this reporting period, the long-term injection test on Unit 1 was executed. Data reduction and analysis of collected samples was initiated.

The carbon selected for the long-term injection test was RWE Rheinbraun's Super HOK carbon. The majority of the test was conducted at carbon injection rates between 4 and 10 lb/Macf. Mercury removal across the ESP ranged from 50 to 91% over the test period, with the majority of the data concentrated between 60 and 85%. The mercury removal across the ESP/JBR scrubber system ranged from 50 to 97%, with the majority of the data concentrated between 70 and 94%. In contrast, baseline (no injection) mercury removals were 50% across the ESP and 80% across the system.

Method 17 traverses were conducted across the ESP outlet duct in order to determine the effect of activated carbon injection on the ESP outlet particulate matter concentration. The Method 17 runs were conducted at various carbon injection rates. Approximately 70% of the collected data fell within or below the range of ESP outlet particulate matter concentrations measured during baseline. For the 30% of data that exceeded the measured baseline concentrations, there did not appear to be any correlation between the magnitude of the carbon injection rate and the ESP outlet particulate concentration. Without a larger data set, it is unclear whether these excursions are attributable to the carbon injection or to other process parameters.

During a two-week period of the injection test, the scrubber slurry samples exhibited a black or unusually dark color. This coloration could indicate a penetration of the carbon through the precipitator. Further examination is being performed on these samples.

2.0 Experimental

2.1 Plant Configuration

Figure 2-1 shows the basic plant configuration, sorbent injection points, and flue gas sample locations for Units 1. Characteristics of the unit are summarized in Table 2-1 and have been described in previous reports.

Table 2-1. Plant Yates Unit 1 and 2 Configurations

	Yates Unit 1	Yates Unit 2
Boiler		
Type	CE Tangential Fired	
Nameplate (MW)	100	
Coal		
Type	Eastern Bituminous	
Sulfur (wt %, dry)	1.0	
Mercury (mg/kg, dry)	0.06-0.14	
Chloride (mg/kg, dry)	150-450	
ESP		
Type	Cold-Side	
ESP Manufacturer	Buell (1968 and 1971 vintage, refurbished in 1997)	
Specific Collection Area (ft^2/1000afcm)	173	144
Plate Spacing (in.)	11	
Plate Height (ft)	30	
Electrical Fields	3	2
Mechanical Fields	4	3
ESP Inlet Temp. (°F)	310	300
ESP Design Flow Rate (ACFM)	490,000	420,000
NO_x Controls	Low NOx Burners	None
SO_2 Controls	Chiyoda CT-121 wet scrubber (JBR)	None
Flue Gas Conditioning	None	Dual NH_3/SO_3

2.2 Experimental Methods

The sorbent injection equipment was described in the first technical report. The mercury measurements for baseline and injection testing were performed with mercury semi-continuous analyzers, which have been described in previous reports. Particulate loading was measured via Method 17 traverses in the duct. During injection testing, Ontario Hydro and Method 17 were conducted.

Solid and liquid samples, such as FGD byproduct slurry, fly ash, and coal, were collected and analyzed for mercury content. Fly ash and coal mercury were digested with ASTM 3684 and analyzed for mercury by CVAA.

2.3 Progress by Task

Progress on the various project tasks are described in the following sections. A summary of progress is provided in Table 2-2.

Table 2-2. Schedule for FY 2004 Milestones for this Test Program

Milestone	Description	Planned Completion	Actual Completion
1	Hazardous substance plan	Q1	Q1
2	Project kickoff meeting	Q1	Q1
3	Site Survey – Units 1 and 2	Q1	Q1
5	Test plan – Units 1 and 2	Q1	Q2
6	Complete sorbent injection system installation for parametric tests – Units 1 and 2	Q2	Q2
7	Complete baseline and parametric tests for sorbent 1 (Darco FGD™ carbon) on Units 1 and 2	Q2	Q2
8	Complete baseline and parametric tests for sorbent 2 (Super HOK carbon) on Unit 1	Q3	Q3
9	Transfer and install ACI silo and feeder system on Unit 1 for long-term tests	Q4	Q4
10	Initiate long-term test on Unit 1	Q4	Q1-FY2005
11	Complete long-term test on Unit 1	Q4	Q1-FY2005
12	Complete data workup for Units 1 and 2	Q2-FY2005	
13	Initiate economic analysis	Q2-FY2005	

Task 1 – Project Planning

Three different sorbents were evaluated in the parametric tests on Unit 1. A description of each sorbent is provided in the Table 2-3. RWE Rheinbraun's Super HOK sorbent was selected for the long-term tests on Unit 1. The sorbent was selected because of its comparable performance and lower cost compared to Norit America's Darco FGD™. Figure 2-2 shows the performance curves for three tested carbons. The percent reduction in vapor phase mercury concentration at the ESP outlet is plotted against the sorbent injection rate. For the Darco FGD™ and the Super HOK, mercury reduction reached a plateau of 35-45% at an injection rate between 6 and 9 lb/Mmacf.

An order was placed for 88,000 lb of sorbent. The sorbent was shipped in two batches from Germany. Transport was by boat to Savannah, GA. The sorbent was shipped in multiple shipments by vacuum truck from Savannah to Plant Yates.

ADA-ES installed and operated the injection process equipment that was used during testing at Yates. The silo and feed train are pictured in Figure 2-3. The silo is 10 feet in diameter, with a sidewall height of 32 ft. The silo had a volume of 2500 ft^3, and accommodated up to 60,000 lb of HOK carbon. The carbon injection system consisted of a bulk-storage silo and twin blower/feeder trains. Sorbent was delivered in bulk pneumatic trucks and loaded into the silo, which was equipped with a bin vent bag filter. From the two discharge legs of the silo, the sorbent was metered by variable speed screw feeders into educators that provided the motive force to carry the sorbent to the injection point. Regenerative blowers provided the conveying air. Flexible hoses carried the sorbent from the feeders to dual distribution manifolds located on the ESP inlet duct. Each manifold supplied six injectors for a total of twelve. The feeding system was calibrated prior to commencement of the long-term injection test. The calibration was verified throughout the injection test by means of level and weight sensors on the silo.

Table 2-3. Sorbents Selected for Test Program

Carbon Name	Manufacturer	Description	Cost ($/lb)
Darco FGD™	Norit Americas	Lignite-derived activated carbon; baseline carbon (19 µm mean particle size)	0.50
Super HOK	RWE Rheinbraun	German lignite-derived activated carbon (23 µm mean particle size)	0.38 [a]
NH Carbon	Ningxia Huahui Activated Carbon Co. LTD (HHAC)	Chinese iodated bituminous-derived activated carbon (24 µm mean particle size)	0.88

a = F.O.B. Pennsylvania

Task 2 – Unit 1 Testing

The Unit 1 parametric testing with Darco FGD™, Super HOK, and NH carbons has been completed and results have been reported in previous quarterly reports. A long-term performance test began in mid-November 2004 and finished in mid-December 2004. The initial plan had been to perform the long-term test during FY04-Q4. However, several factors resulted in a delay in the initial schedule; these factors were associated with plant operation during ozone attainment season and a Unit 1 outage during October. It was thus determined that the best time to perform the long-term test was November-December, 2004.

Task 3 – Unit 2 Testing

The Unit 2 parametric testing with Darco FGD™ carbon has been completed and results have been reported in previous quarterly reports.

Task 4 – Data and Economic Analysis

Data analysis of the parametric tests on Units 1 and 2 has been completed and is reported in previous quarterlies. Reduction of data gathered during the long-term injection test has begun. Preliminary results are reported in this quarterly report. No activity was conducted related to the economic analysis.

Task 5 – Waste Analysis and Byproduct Sampling

Samples of fly ash and gypsum byproduct were collected during the long-term ACI test on Unit 1. The collected samples will be shipped to a designated laboratory for testing as part of NETL's Waste and Byproduct Characterization program.

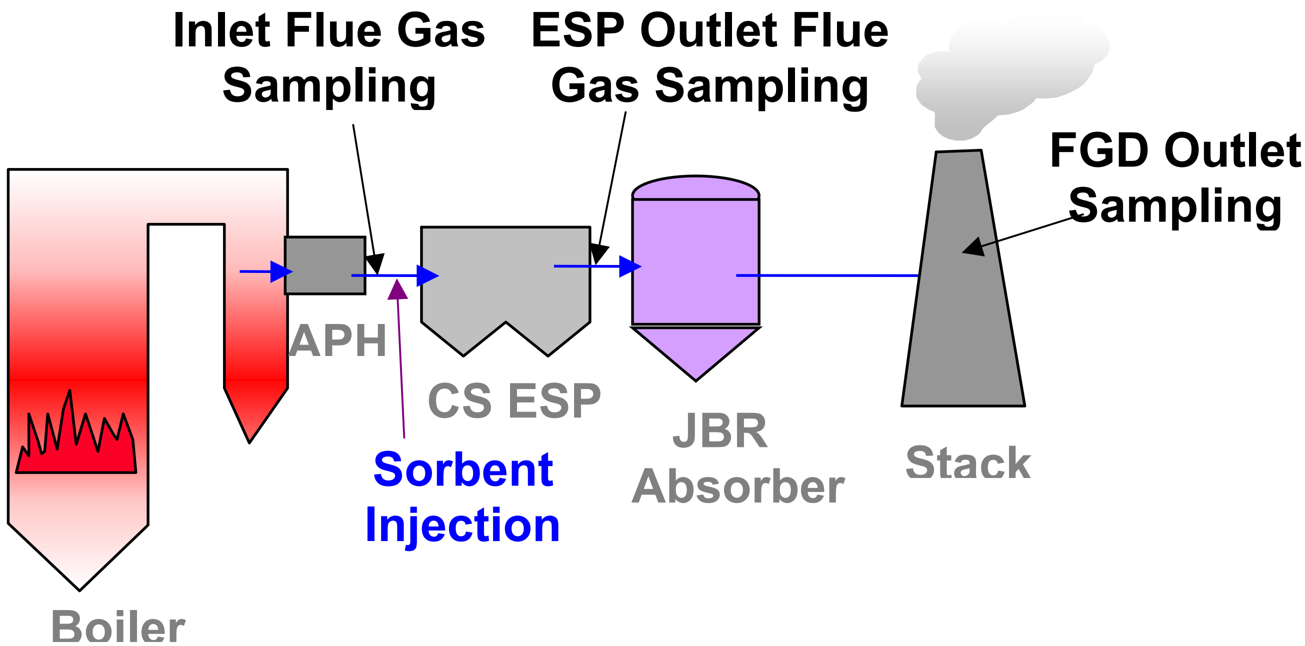

Figure 2-1. Unit 1 Configuration and Flue Gas Sample Locations

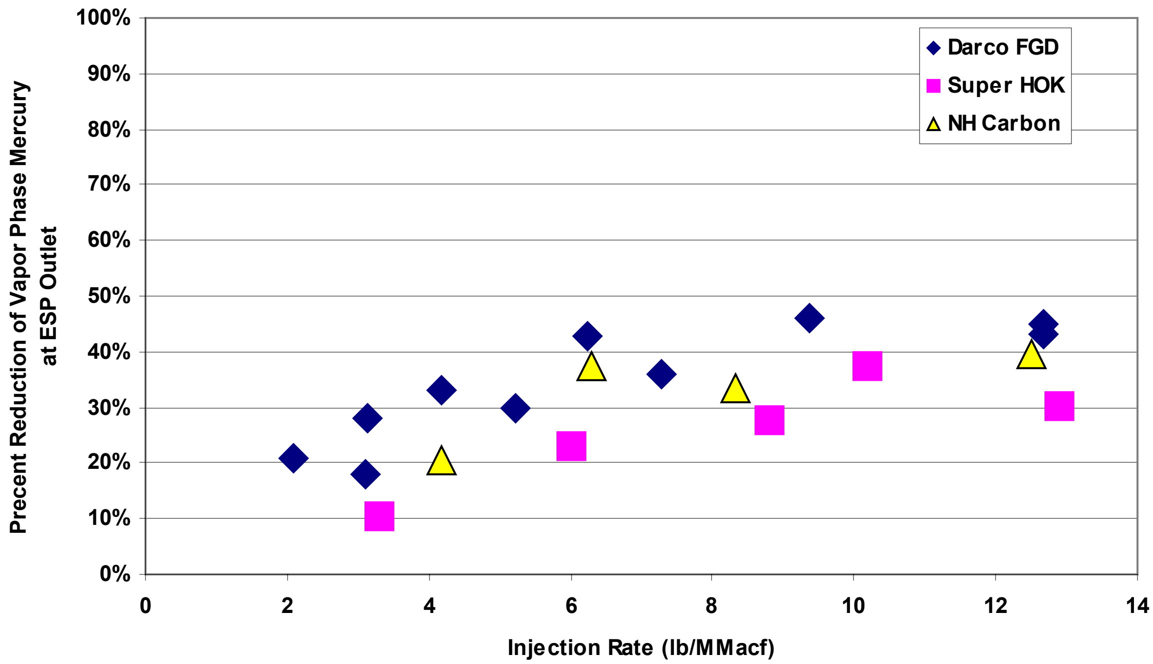

Figure 2-2. Reduction in Vapor Phase Mercury Concentration at ESP Outlet for the Three Sorbents Tested in the Unit 1 Parametric Tests

Figure 2-3. Carbon Injection Storage Silo/Feeder Train (Long-Term Testing)

3.0 Results and Discussion

A month-long activated carbon injection test was conducted at Plant Yates Unit 1 with RWE Rheinbraun's Super HOK activated carbon. For the majority of the injection test, Unit 1 operated at a load set by grid demand. This load was typically 55 MW. During one week of the test, Unit 1 operated at full load (107 MW) during the 6 am – 6 pm time period, and operated at reduced load overnight.

Figure 3-1 shows the mercury concentration measured at each of the SCEM locations, along with the carbon injection rate. The mercury concentrations are represented in μg/dry Nm^3 at 3% O_2. The carbon injection rate is in lb/Macf. The data are plotted as hourly averages (the SCEM generates data every 3 to 4 minutes). Figure 3-1 spans the entire month of the injection test as well as baseline data taken both prior and subsequent to the injection test.

Figure 3-2 shows the percent vapor phase mercury removals that were calculated from these data. Two removal values are charted: the vapor phase mercury removal across the ESP, and the vapor phase removal across the ESP/JBR scrubber system.

Baseline mercury removal across the Unit 1 gas path was characterized before the start of the long-term injection test and again at the end of the test. Because the HOK carbon was injected downstream of the ESP inlet measurement location, the ESP inlet values were not affected by the carbon injection. The ESP inlet mercury concentration ranged from 5 - 13 μg/Nm^3 during baseline and injection testing, with 60-75% oxidation.

At the ESP outlet, the baseline vapor phase mercury concentration ranged from 3 - 7 μg/Nm^3, with 55-80% oxidation. At the stack, the baseline vapor phase mercury concentration ranged from 1.5 to 3 μg/Nm^3. Baseline removal across the ESP was nominally 50%, and baseline removal across the system (ESP+JBR scrubber) was 70-80%. The baseline mercury removal measured across the ESP is in agreement with results measured during the baseline testing in Spring 2004. The baseline removal across the system was higher during the Fall 2004 testing than during the Spring 2004 tests. The mercury oxidation levels at the both the ESP inlet and outlet were also higher, indicating a possible explanation for the higher overall removal.

The carbon feed rate was adjusted throughout the injection test, in order to investigate the effect on outlet mercury concentrations. The effective carbon feed rates varied somewhat throughout the test period because of these manual adjustments and because of load, flow, and temperature variations during the testing. Because the flue gas flow rate changes with load, the carbon injection rate (lb/hr) was adjusted with load to maintain a constant volumetric-based injection rate (lb/Macf).

During the month-long test period, there were a few periods each consisting of several hours where the carbon injection rate dropped to zero. The carbon feeding occasionally stopped because of mechanical or electrical problems that occurred with the feed skid during the night and were not fixed until staff arrived on-site the following morning. For other short periods, the carbon injection rate was raised to as high as 16 lb/Macf in order to evaluate the effect on the ESP outlet particulate matter concentration. Excluding these brief periods of zero- and high-injection rates, the carbon injection rates was typically between 4 and 10 lb/Macf during the long-term test period.

Table 3-1 shows the range of vapor phase mercury removals measured across the ESP and across the system. As seen in Table 3-1 and Figure 3-2, there was significant variability in the mercury removal performance achieved during the test. Mercury removal across the ESP ranged from 50 to 91%, with the majority of the data concentrated between 60 and 85%. The mercury removal across the ESP/JBR scrubber system ranged from 50 to 97%, with the majority of the data concentrated between 70 and 94%. From Table 3-1, it appears that increases in the carbon injection rate above 4.5 lb/Macf did not result in significant changes in the range of mercury removals measured.

Table 3-1. Range of Vapor Phase Mercury Removals Measured during Long-Term Injection Test

Injection Rate (lb/Macf)	Time Period	Range of Vapor Phase Hg Removals Measured across ESP (%)	Range of Vapor Phase Hg Removals Measured across System (%)
4.5	11/23 17:00 – 12/5 5:00	50 – 91*	71 – 96
6.5	11/18 17:00 – 11/22 12:00	64 – 86	71 – 94
9.5	11/16 17:00 – 11/18 11:00; 12/11 0:00 – 12/13 4:00	67 – 86	75 – 92

* For the mercury removal across the ESP at an injection rate of 4.3 lb/Macf, 91 % removal was measured during one single hour; otherwise, the highest measured vapor phase mercury removal was 86%.

In Figure 3-3, the vapor phase mercury concentrations at the ESP outlet and the stack are plotted in lb Hg/trillion Btu. The proposed emission limit for bituminous coal fired power plants is 2 lb Hg/trillion Btu. As seen in this plot, with no carbon injection, the ESP outlet concentration was between 2 and 3 lb/trillion Btu, while the stack mercury concentration was between 0.7 and 1.3 lb/trillion Btu. With carbon injection, the ESP outlet mercury concentration ranged from 0.4 to 3.2 lb/trillion Btu. The proposed 2 lb/trillion emission rate was exceeded when the ESP inlet mercury was at its highest concentrations (12-16 $\mu g/Nm^3$), which was almost twice the typical value seen over the month-long test.

Ontario Hydro measurements were made at the ESP outlet and the stack. Ontario Hydro measurements were not made at the air heater inlet, because of cyclonic flow problems that made isokinetic sampling impossible and a reactive ash that adsorbed mercury in previous Ontario Hydro testing (see Quarterly Technical Progress Report, April-June 2004). The Ontario Hydro results were not available as of the end of the quarter.

Collection and Analysis of Solids Samples

Coal, ash, and FGD byproduct samples have been selected for analysis. Results will not be available until next quarter.

Samples of Unit 1 fly ash and gypsum byproduct were collected during the long-term test for the DOE Waste and Byproducts Analysis study. Table 3-2 list the samples obtained during this reporting period. These samples will be stored with previously obtained byproduct samples until NETL designates the laboratory to which they will be shipped.

Table 3-2. Samples Collected for DOE Byproducts Study

Date	Sample Type	Number of Samples
12/1/04	Unit 1 Ash from #2 Hopper	1 5-gallon bucket
12/1/04	Unit 1 Ash from # 3 Hopper	1 5-gallon bucket
12/1/04	Unit 1 Ash from #6 Hopper	2 5-gallon buckets
12/1/04	Unit 1 Ash from #7 Hopper	1 5-gallon bucket
11/30/04 – 12/2/04	Unit 1 JBR Gypsum Sample	3 5-gallon buckets

Effect of Carbon Injection on ESP Operation

EPA Method 17 traverses were conducted at the ESP outlet in order to quantify particulate matter breakthrough. The Method 17 traverses were conducted at various load and injection rate conditions. Figure 3-4 shows the measured ESP outlet particulate concentration (in lb/MBtu). Baseline (no injection) and parametric HOK-injection data from the Spring 2004 testing are also included. The baseline data from Spring 2004 were conducted with a duct traverse, while the parametric injection data from Spring 2004 were single point measurements.

The baseline ESP outlet particulate concentration ranged from 0.040 to 0.085 lb/MBtu. Method 17 traverses were conducted for carbon injection rates ranging from 3 to 17 lb/Macf. Of these data, 70% of the measurements represented concentrations that were within or less than the range of ESP outlet concentrations measured during baseline testing. The particulate concentrations that exceeded the baseline values did not appear to correlate to the magnitude of the sorbent injection rate. It is possible that some other unit operation parameter may have caused re-entrainment or sneakage of some particulate matter. The highest ESP outlet particulate concentration measured was approximately four times greater than the baseline concentration. All of the excursions were at or above the NSPS regulation of 0.1 lb/Mbtu for a small-SCA ESP. For Plant Yates, which operates with a downstream scrubber, these occasional excursions seen during activated carbon injection are of less regulatory significance. However, for units with small-SCA ESPs and no further downstream particulate control, these excursions may be of significance.

The sample set of Method 17 runs collected during carbon injection is ten times larger than the sample set for baseline operation. Therefore, it may be possible that particulate concentration excursions occur during baseline operation, but were not captured during the limited baseline sampling.

ESP performance during long-term activated carbon injection will be characterized by evaluating the arc and spark rate during injection testing. The analysis of the data is not completed, so results will be presented in a future quarterly.

During the Spring 2004 parametric tests, significant arcing was noted. However, with the available data it was not possible to directly correlate the arcing to specific injection conditions. In the time that elapsed between the parametric tests and the long-term injection tests, the Unit 1 ESP underwent rigorous inspection and maintenance. The stand-off insulators at the bottom of the high voltage frame were found damaged or broken. It is unclear when this damage occurred (i.e. whether the damage is related to activated carbon injection). It is believed that the presence of broken insulators would lead to erratic arcing and sparking behavior in the ESP, as was observed in the Spring 2004 testing. A visual inspection of the insulators revealed that carbon was “baked” onto the surface of the insulators. This can be clearly seen in Figure 3-5.

Prior to commencement of the injection test, the insulators on the Unit 1 ESP were replaced. A unit outage is planned during the next quarter. The internals of the ESP will be inspected at that time in order to evaluate the condition of the ESP and the effect that activated carbon may have had. These observations will be summarized in the next quarterly report.

Effect of Carbon Injection on Scrubber Operation

Samples of the JBR scrubber slurry were taken periodically. During the period of 25 November through 10 December the scrubber slurry was observed to be either black or dark in color. During this time period, the carbon injection rate typically ranged from 4 - 6 lb/Macf (with a few, brief periods at higher rates). The scrubber slurry was its darkest color November 25-29, with its color slowly lightening over that time period. Prior to and subsequent to this time period, the scrubber slurry did not show any visual evidence of carbon contamination. In the subsequent time period, the carbon injection rate was as high as 12 lb/Macf, yet no further darkening was observed. From this limited set of data, it does not appear that the breakthrough of carbon to the JBR scrubber is directly related to the magnitude of the carbon injection rate. Furthermore, while occasionally high particulate concentrations were measured at the ESP outlet, no visible sign of carbon was noted on any of the Method 17 filters.

Slurry samples that have visual signs of contamination and some samples that appear “normal” will be analyzed to quantify the difference in inert content. Based upon these results, further analyses may be conducted. All laboratory analyses of the JBR scrubber byproducts will be conducted in the next quarter.

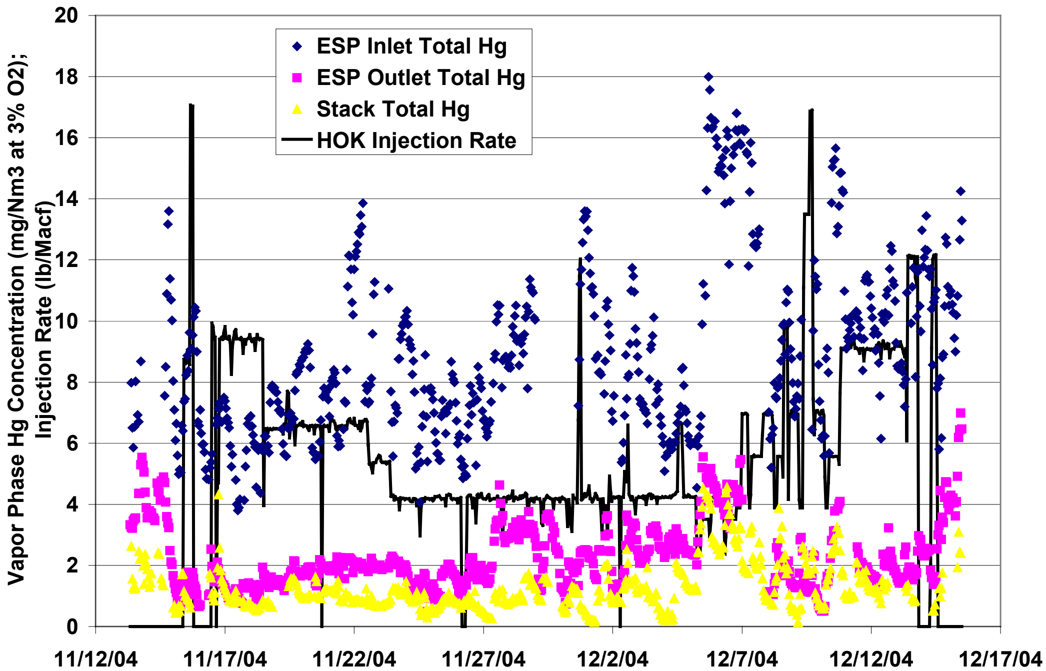

Figure 3-1. Vapor Phase Mercury Concentrations (in µg/Nm^3 @ 3% O_2) Measured at Each SCEM Location During Long-Term Test

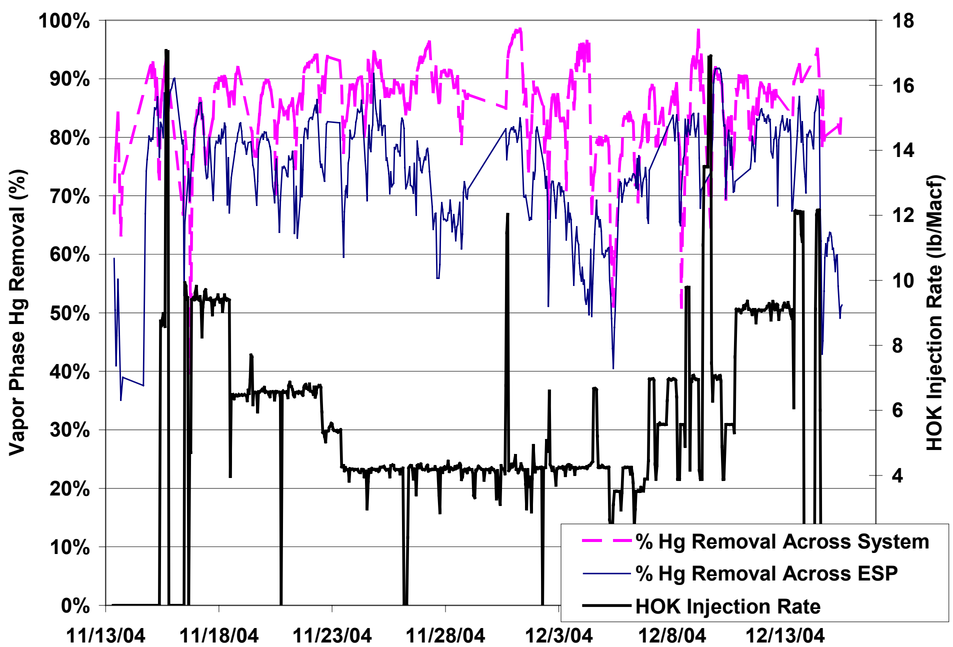

Figure 3-2. Vapor Phase Mercury Removals Measured Across ESP and Across ESP/JBR System During Long-Term Test

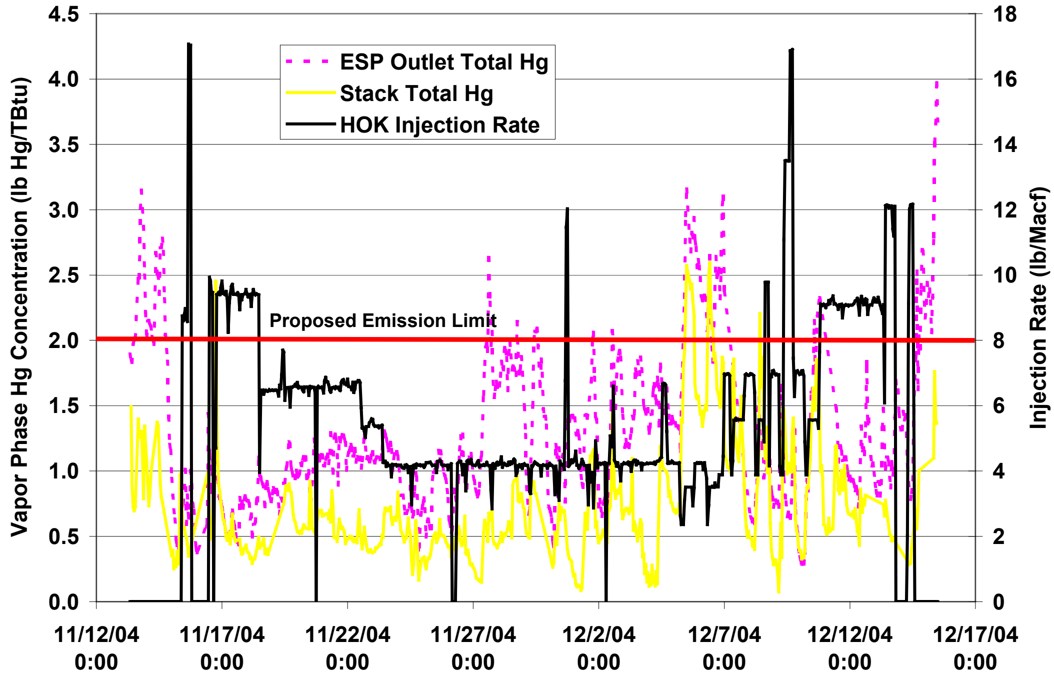

Figure 3-3. ESP Outlet and Stack Mercury Emissions in lb/trillion Btu

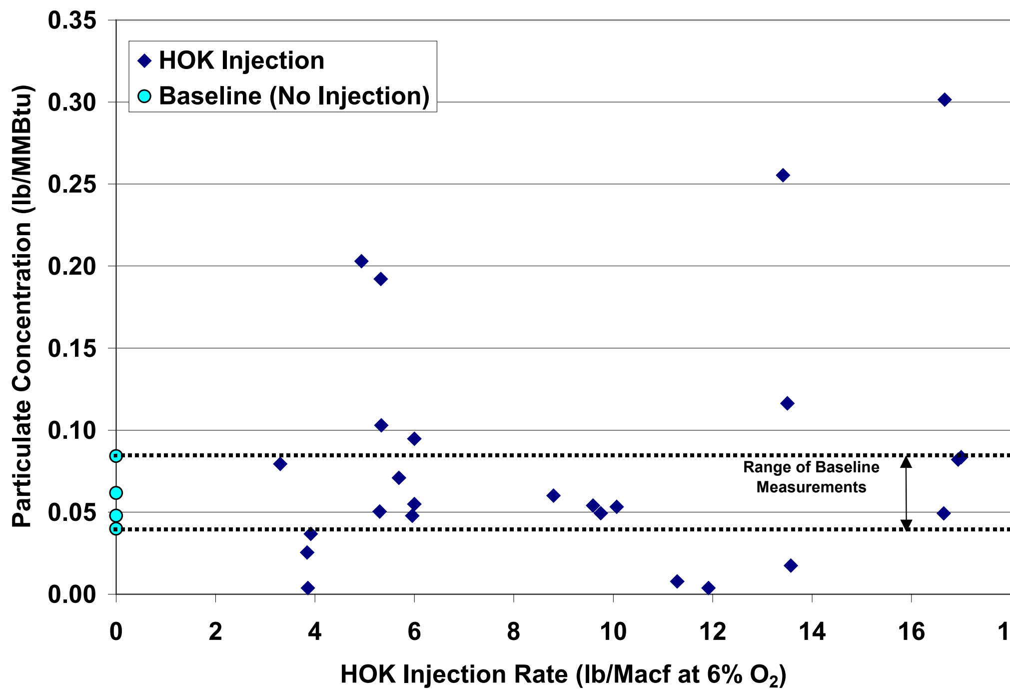

Figure 3-4. ESP Outlet Particulate Concentrations Measured during Baseline and Long-term Injection Tests

Figure 3-5. Damaged insulator from Yates Unit 1 ESP

4.0 Conclusions

During this reporting period, the long-term injection test on Unit 1 was executed. Data reduction and analysis of collected samples was begun.

The carbon selected for the long-term injection test was RWE Rheinbraun's Super HOK carbon. The majority of the test was conducted at carbon injection rates between 4 and 10 lb/Macf. Mercury removal across the ESP ranged from 50 to 91% over the test period, with the majority of the data concentrated between 60 and 85%. The mercury removal across the ESP/JBR scrubber system ranged from 50 to 97%, with the majority of the data concentrated between 70 and 94%. In contrast, baseline (no injection) mercury removals were 50% across the ESP and 80% across the system.

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During a two-week period of the injection test, the scrubber slurry samples exhibited a black or unusually dark color. Further examination is being performed on these samples.

5.0 Activities Scheduled for Next Quarter

The next quarterly reporting period covers the period January 1, 2005 through March 31, 2005. The primary activities planned for this period include completion of solids analyses of samples gathered during long-term injection test, continue investigation on ACI ESP impacts, further data analysis of long-term injection data, and initiation of the economic analysis and site report. During this coming quarter, a second set of parametric tests will be conducted on Plant Yates Unit 1 with different sorbents from the ones tested during the Spring 2004 tests.

6.0 References

None for this document.